Document Release Authorization To IMS

Los Alamos National Laboratory

PO Box 1663 MS H816
Los Alamos, NM 87545

This is a milestone document: ☐ **YES** ✔ **NO**

Doc No:	LA-UR-03-8756	Release Date:	11/19/03
Title:	Estimation of Steam Generation Rate and Minimum Burst Disk Size for the Isolation Gas System		
Author(s):	Keith Woloshun, Los Alamos National Laboratory at Paul Scherrer Institute		

Approved for Release

Approved by	Typed Name	Date	Signature
Principal Author:	Keith Woloshun	11/19/03	[redacted]
LANL Program Manager:	Michael W. Cappiello	12/03/03	

Estimation of Steam Generation Rate and Minimum Burst Disk Size for the Isolation Gas System

Summary

Calculation of the steam generation rate was made in the event of an instantaneous D_2O leak into the IGS (Isolation Gas Space). An upper bound result is necessary to adequately size a burst disk that will limit the pressure in the IGS to 10 bar. A quasi-steady state energy balance was used to calculate the steam production as a function of time, using conservative estimates of the thermal coupling between the hot target parts and the D_2O. The resulting steam production rate is 60 l/s (0.24 kg/s) at the time the pressure reaches 10 bar. A burst disk diameter of 12 mm is the minimum acceptable. A commercially specified burst disk for this flow rate would be about 18 mm (Ref 6).

Scenario Description, with Initial and Boundary Conditions

This evaluation is an upper bound calculation of steam generation rate in the event of a heavy D_2O leak into the IGS (Isolation Gas Space). The IGS is the space between the D_2O-cooled Lower Target Enclosure (LTE) and the Lower Liquid Metal Container (LLMC), plus the space between the upper target (including the heat exchanger) and the Upper Target Enclosure (UTE), plus the open space within the upper target around the shielding and within the Target Head (TH). The total volume of the IGS is 59.1 l (Ref 1), with the spatial distribution as indicated in Table 1.

Table 1. VOLUME DISTRIBUTION IN THE IGS

Location	Volume (liters)
Lower Target	13.06
Heat Exchanger	23.08
Upper Target	5.69
Target Head	15.95
Piping (up to burst disk)	1.32
TOTAL	**59.10**

In the event of a leak in the D_2O system, isolation valves will start to close after 4 l has been lost. The valves close in 2 seconds, during which an additional 4 l of heavy D2O will pass the valves and leak. Once the valve have closed, in addition to this 8 l already leaked, there is 4.3 l more in the piping on the target side of the isolation valves (Ref 2) and 9 l in the LTE. The total available D_2O inventory is then 21.3 l.

This evaluation assumes that the accident scenario is a leak of D_2O only into the IGS. It has previously been shown that a D_2O leak cannot initiate a LBE leak (Ref 3) and that an LBE leak does not rupture the LTE and cause a D_2O leak (Ref 4). In other words, a combined D_2O-LBE leak is not a credible accident to be considered herein.

Initial and boundary conditions are listed and described below:

1. D_2O leak is instantaneous, up to the level of the top of the safety hull. The maximum volume of D_2O that can leak is 21.3 liters: 4 l before valves are triggered to close, 4 l additional during the 2 s required to close the valve, 4.3 l in the piping below the valves, and 9 l in the safety hull. However, the total volume of the Lower Target is 13.1 l, so the remaining 8.2 l remains in the safety hull during the critical time up to safety disk bursting. Although an instantaneous leak of all the D_2O is no only unlikely but impossible, it is necessary to establish an upper bound on the D_2O inventory and, most important, the wetted area for heat transfer (boiling).

2. Wetted surface extends up to the top of the heat exchanger. It is expected that D_2O boiling in the narrow gap (5 mm annulus) of the IGS will result in a large vapor fraction rapidly rising to the free surface. D_2O will be entrained in this process and wet hot surfaces above. The precise nature of the boiling dynamics is difficult to predict. This assumption of D_2O filling the space and wetting all surfaces up to the top of the heat exchanger doubles the surface area for heat transfer and nearly triples the volume of the D_2O-steam mixture. Since the rising steam blankets some of the hot surface from the D_2O, the slugging process in fact effectively reduces the heat transfer surface area (wetted area) intermittently, at least locally, while increasing it elsewhere. This assumption is considered conservative, but in fact some D_2O may be pushed higher, wetting surfaces in the upper target, shielding area, and target head. It is difficult to quantify the amount of D_2O that may be so displaced, and also difficult to predict evaporation rates. It is deemed reasonable to neglect this possible contribution because of the lower temperatures in this region, the forces required to raise a significant volume of D_2O to this height under these conditions, and the relatively convoluted path into these regions.

3. The LBE and DTHT pumps remain on; thus continuously cooling the LBE by way of the THX. As the LBE is cooled, the DTHT inlet temperature is held constant at 140…C. The LBE temperature drops at the inlet and outlet while the DTHT temperature drops at the outlet. Heat exchanger effectiveness is recalculated at each time step by a LMTD (log-mean temperature difference) approach. If the pumps are turned off, the steam generation rates are much lower after the initial quench of he outer surfaces of the target. In this case, heat transfer is limited to conduction. This is approximately a 10-fold reduction in the lower target. In the area around the heat exchanger, the time constant by conduction in the steel mass is about 2.6 s, so by the time the 10 bar limit is reached, the heat transfer to the D_2O from this area is very low. However, the total steam production increases significantly because the DTHT is no longer serving as a heat sink. This has no bearing on burst disk size, but is an important factor in sizing the steam condenser.

4. The beam is interrupted immediately (no beam heating of the D_2O).

5. Heat transfer coefficients are: LBE to LLMC -- 3400 W/m^2-C, LBE to outer heat exchanger wall -- 11000 W/m^2-C, water side (boiling) -- 100,000 W/m^2-C. The LBE heat transfer coefficients were calculated using published Nusselt number correlations and are consistent with target design values. The boiling heat transfer coefficient of 100000 is an upper bound flow boiling heat flux (Ref 5). Although the pool of D_2O is in principle stagnant, in which case a heat transfer coefficient of 40,000 would be a better estimate, it is assumed that the slugging of water vapor towards the surface enhances heat transfer, approximating a flowing 2-phase situation. In the early times when the temperature differences are large, film boiling will significantly reduce heat transfer. However, the vapor film on a vertical surface will rise, exposing the surface to fresh liquid. The net result is a somewhat lower heat transfer coefficient, but because of the uncertainty in predicting actual conditions, the upper bound value will be used for all times and conditions.

6. Heat transfer to the D_2O in the region of the heat exchanger is highly exaggerated for reasons of simplicity and to establish an upper bound. The coefficient of 11,000 W/m^2-C applies to the outer wall of the annulus in the cooling holes in the THX block. The cooling holes are 4 mm from the outer wall of the THX block (where the D_2O boiling would occur) at the nearest points. The assumption used in these calculations is a ring 4 mm thick, with flowing LBE on one side and the effectively flowing D_2O on the other. This is very conservative.

7. At time zero the temperature gradient in the steel walls in contact with the IGS is nearly zero. Wetting with D_2O results in extremely high heat transfer for a brief period of time. This is equivalent to quenching a block of steel in water. This effect is ignored in this calculation because the time is short. The time constant for the steel walls to establish equilibrium with the new outer wall cooling condition is 0.2 s, so the most rapid effects are over in less than 1 s.

8. Equilibrium between steam and liquid D_2O is assumed at all times. In fact, the steam will be superheated to some extent. This will result in pressures higher than expected based on the equilibrium assumption, so will result in reaching the 10 bar burst pressure sooner than estimated by these calculations, but the most important parameter, the rate of steam generation after the bursting of the safety disk, is not significantly affected by this assumption.

9. The Upper Target Enclosure, safety hull and any D_2O remaining therein are not accounted for in the energy balance. In other words, the safety hull inner wall is effectively an adiabatic surface. This approximation is conservative, as this mss can be expected absorb some fraction of the energy transferred from the target.

10. The low pressure helium in the IGS is assumed to have no effect on heat transfer or overall system pressure.

11. Initial temperatures are D_2O at 50 C, LBE at 240 in the downflowing annulus of the target at the wall shared with the IGS, and 340 C LBE entering the THX. For heat transfer to D_2O in the THX region, the average LBE temperature (initially 290 C, steadily dropping thereafter).

12. The thermal capacitance of the target was based on the assumption of 900 kg of LBE and 1000 kg of steel.

Calculation Methodology

An Excel spreadsheet was used to develop a quasi-steady state model of steam generation. Up to the time when 10 bar pressure is reached and the burst disk bursts, the D_2O temperature is allowed to rise in 10 degree increments. The energy required to effect this change is calculated from the sum of the amount of steam that must be produced for the corresponding pressure rise based on the latent heat of vaporization of D_2O and the sensible heating of the liquid. The time required to transfer this energy was calculated using the heat transfer assumptions described above. The total mass D_2O evaporated and the volumetric steam generation rate during this time step are calculated. New temperatures for the target are calculated, to be used in the next time step.

The 10 bar burst pressure is reached at 180 C D_2O temperature. After this point, there is no further sensible heating of the liquid; all energy transferred goes into steam production. Pressure does not increase further but is assumed to remain constant. The methodology is changed slightly in that the time step is set and based on heat transfer rates the steam generation rate is calculated. The steam generation rate slowly decreases at the target cools, primarily be heat transfer to the HTHT.

A burst dick size required to relieve the steam at the rate of generation is calculated at each time step, assuming Mach 1 flow condition at the disk. This is the theoretical limit. A disk sized to this condition can be expected to not keep up with steam generation initially. The movement of steam into a pipe at near vacuum and with cold walls is very complex, with condensation in the vapor and on the walls. A disk sized for Mach 0.5 steam exit speed is calculated. This more conservative disk size will result in a pressure decrease within the IGS immediately upon bursting. This effect is not calculated, but assumed to be a beneficial event. The actual size of the burst disk should be based on manufacturers recommendations based on the steam generation rate at the time of disk burst.

Calculation Results

The critical parameters are the rate of steam generation and the hole size required to maintain the pressure at 10 bar or less. Figure 1 shows the steam generation rate as a function of time after leak, and the pressure inside the IGS, assuming the pressure does not reduce after the disk burst. The step increase in steam generation rate at the pressure where the safety disk bursts is due to the fact that the liquid D_2O no longer heats up, so all the energy transferred to the D_2O goes to the production of steam.

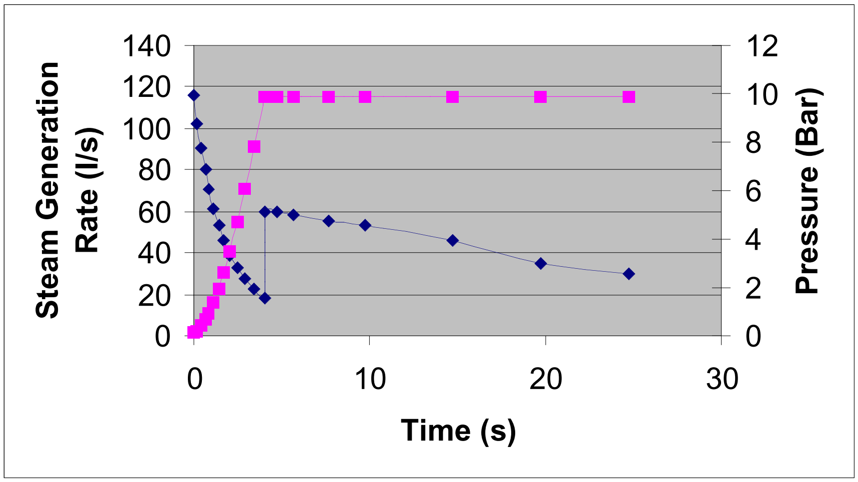

Figure 1. Plot of steam generation rate and pressure in the IGS as a function of time after a leak event.

The minimum disk size required to vent the steam at Mach 1 and 10 bar is 12 mm diameter. A burst disk size of 16.6 mm diameter corresponds to a Mach 0.5 exit velocity. A commercially sized disk for this flow rate is 1.8 cm (Ref. 6). However, the exit velocity is not an independent parameter. An oversized disk will initially allow steam to exit faster than it is produced, thus reducing the pressure inside the IGS.

Conclusion

The burst disk should be sized for a steam generation rate of 60 l/s at 10 bar, based on manufacturers recommendations. The theoretical minimum, based on a Mach 1 flow condition, is 12 mm diameter. . A commercially specified burst disk for this flow rate would be about 18 mm (Ref 6).

References

1. Welte, J., Insulating Gas Volumen im MEGAPIE-Target , electronic document, October 3, 2003.
2. Dubs, M., Targetfensterkuehlung: Volumen in D2O Leitung , electronic document, October 3, 2003.
3. Smith, B. L., Thermal Shock Transient: CFD Simulation of Water Jet Impaction on Target Window, MEGAPIE Technical Review Meeting, Paris, March 18-19, 2003.
4. Ni, L. , Structural Mechanics and Heat Transfer in the MEGAPIE Lower Target Enclosures at Normal Operations and Hypothetical Accident Conditions, 2002.
5. Lienhard, J., A Heat Transfer Textbook˚ , Prentice-Hall, 1981.
6. BS&B Safety Systems, Catalogue 77-1005, online at www.bsbsystems.com.

PAUL SCHERRER INSTITUT

	Registrierung TM-34-03-16
Titel **Estimation of Steam Generation Rate and Minimum Burst Disk Size for the Isolation Gas System**	Ersetzt
Autoren/ Autorinnen Keith Woloshun	Erstellt Nov 19, 2003

Zusammenfassung:

Calculation of the steam generation rate was made in the event of an instantaneous D_2O leak into the IGS (Isolation Gas Space). An upper bound result is necessary to adequately size a burst disk that will limit the pressure in the IGS to 10 bar. A quasi-steady state energy balance was used to calculate the steam production as a function of time, using conservative estimates of the thermal coupling between the hot target parts and the D_2O. The resulting steam production rate is 60 l/s (0.24 kg/s) at the time the pressure reaches 10 bar. A burst disk diameter of 12 mm is the minimum acceptable. A commercially specified burst disk for this flow rate would be about 18 mm.

/erteil Abt.	Empf nger / Empf ngerinnen	Expl.	Abt.	Empf nger / Empf ngerinnen	Expl.		Expl.
	Friedirch Groeschel Werner Wagner Hejo Heyck Stefan Joray					Bibliothek	
						Reserve	
						Total	
						Seiten	
						Beilagen	
						Informationsliste D 1 2 3 4 5 8 9 A	
						Visum Abt./Laborleitung:	